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WATER-GAS APPARATUS AND THE USE OF CENTRAL DISTRICT COAL AS GENERATOR FUEL

BY

WILLIAM W. ODELL

ILLINOIS COAL MINING INVESTIGATIONS
COOPERATIVE AGREEMENT

[This paper was prepared under a cooperative agreement with the Illinois State Geological Survey and the Engineering Experiment Station of the University of Illinois through its department of Mining Engineering]

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WATER-GAS APPARATUS AND THE USE OF CENTRAL DISTRICT COAL AS GENERATOR FUEL.

BY WILLIAM W. ODELL.

INTRODUCTION.

By reason of the greatly increased cost of the gas oil used to enrich water gas, and the higher costs of coal and labor, many gas companies, especially those having franchises that call for the delivery of gas of a certain quality at a certain price per thousand feet, are having financial difficulties. Reconstruction of plants to manufacture coal gas instead of water gas is difficult if not economically impossible under present conditions. The situation calls for the use of practicable economies and methods. One of these economies is the use of cheaper grades of coal to replace anthracite or coke. In the course of its investigations for increasing efficiency in the use of fuel the Bureau of Mines has given attention to various problems bearing on the manufacture of water gas. This paper presents certain preliminary studies made while considering the possibility of substituting Indiana and Illinois coal for coke in water-gas generator sets.

MODERN WATER-GAS APPARATUS.

Although many patents have been issued for different styles and designs of water-gas apparatus, the ideas on which modern apparatus for the manufacture of water gas are based seem to have originated with T. S. C. Lowe, of Norristown, Pa. In 1875 a patent issued to him covered a separate fixing chamber heated internally by the combustion of gas. This principle is used in all water-gas sets of recent design.

Prof. Lowe indicated the importance of and the benefits from the vaporization of the carbureting oil in the presence of hydrogen. He appreciated the advantage thus gained although he did not know the chemical reactions that took place. The advances he made in his studies of gas manufacture seem to be as follows:

Heating a fixing vessel or carbureter by internal combustion.

Using blast gases from the generator (gases heretofore wasted) for heating the carbureter.

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Indicating the benefits derived from the vaporization and fixing of the carbureting oil in the presence of hydrogen.

Designing an apparatus that could be used either with light, volatile oils, such as naphthas, or the heavier gas oils commonly used.

Using superheated steam.

Using waste-heat boilers.

Immediately after the appearance of the Lowe apparatus numerous other designs appeared. Most of these used the Lowe principles but differed in various ways. Some types used two generators, some two fixing chambers, and some two generators and two fixing chambers. In the process of evolution the chambers were brought closer together and some designs appeared having the shells placed one on top of the other for the purpose of decreasing radiation losses and reducing the area of ground space required for a given capacity. An example of this type observed is the Springer set in which the fixing chamber is placed directly over the generator, and a more recent example is the Williamson, in which the carbureter and superheater are in one shell directly on top of the generator. A vertical wall divides this shell into two checker chambers.

The increasing output of heavy oils and the simultaneous decrease in the amount of light oils available for gas making have led to the design of apparatus capable of utilizing oils of higher boiling points, such apparatus having a double superheater or a carbureter and superheater. In a later design the superheater was made higher for the double purpose of increasing the fixing surface and creating a natural draft for the generator. This draft tended to prevent the gas from back-firing or flashing back in the face of the operator at the charging door when fuel was being charged into the generator.

The up-and-down run was an advance in the art that was made in 1891.

Search of the patent records and technical literature shows that many attempts have been made to use bituminous coal as generator fuel, with varying success. Some of the more prominent objections that have so far prevented the general use of coal in place of coke fuel are as follows:

1. Bituminous coal on burning yields tar which gums the valves, charging doors, etc., with the result that valves stick and doors leak.

2. Freshly charged fuel can not be raised in temperature rapidly because of its containing moisture and volatile matter.

3. Upon coking the fuel mats together and obstructs the passage of air and steam so that blowholes form in the fuel bed.

4. Capacity is decreased, chiefly by 2 and 3.

5. The zone of incandescent fuel in the generator is smaller because of the presence of coking coal.

6. The proportion of CO_2 in the gas is increased as the smaller size of the hot zone lessens the time of contact of the steam and hot fuel.

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7. More heat (as heat of combustion) enters the blast gas than is required to heat the checker chambers.

8. The difficulty of using waste-heat boilers, wherein the sensible heat of the finished gas is utilized, is increased by the larger production of tar, as flues of the waste-heat boilers rapidly become clogged with tar and carbon.

9. Checker chambers are overheated when the blast gas is all burned within the set.

10. Most bituminous coal is friable, readily breaking into smaller pieces on handling.

11. Much bituminous coal has a higher sulphur content than coke.

Realizing that the coal could not enter into the water-gas reaction with steam until it became incandescent, several investigators devised apparatus intended to insure the coal being completely carbonized before it reached the generator. In other words, a retort was so placed that some of the heat from the blast gas was transmitted to it and the coal within it was coked. The results, however, were not satisfactory, chiefly because more heat was required for carbonizing the coal than was available with the methods employed as excess heat in the blast gases.

One form of apparatus—the Loomis—designed for use with coal fuel differed from others in that it was built for down runs and blows and had a superheater provided with numerous closely spaced walls instead of the usual checker brick, the idea of the latter being to prevent the deposit of ashes or soot. In the Rose Hastings type, designed for a similar purpose, four fuel beds were placed adjacent to one another and connected. Oven coke was charged in one of these generators and in the others mixtures of coal and coke were used. The fires were all blown together and the run made as follows: Steam was introduced into the mixed fuel beds and the water gas produced was led through the superheating chambers with carbureting oil and finally through the coke bed for fixing.

Another type, the Fahnehjelm apparatus, was a single shell set. The generator was extended vertically, forming a coking retort above the lower portion which constituted the generator proper. Regular up-and-down steam runs were made, but the blast gases were taken off at the middle of the fuel bed and passed through a checker chamber surrounding the retort section of the generator. The heat generated from the combustion of the gas around the retort and that from the up runs was supposed to carbonize the coal before it progressed far into the generator proper. The secondary air was admitted through specially provided air ports toward the middle of the fuel bed in the generator proper. While there is merit in the ideas expressed in some of the numerous attempts to devise apparatus for use with bituminous coal, the fact remains that the difficulties were not

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eliminated in any of them to such an extent that they have replaced apparatus designed for coke fuel.

In the Rew apparatus, figure 1, the coal was periodically fed into an inclined retort that led directly to the generator. The sets were always in duplicate and were operated in such a way that one was dependent on the other. Blast air was admitted below the grates of both generators simultaneously. The blast gas passed over the coal in the retorts and then down through the regenerators, which consisted of two checker chambers, one superimposed on the other, in one shell. Additional primary air was also admitted below the

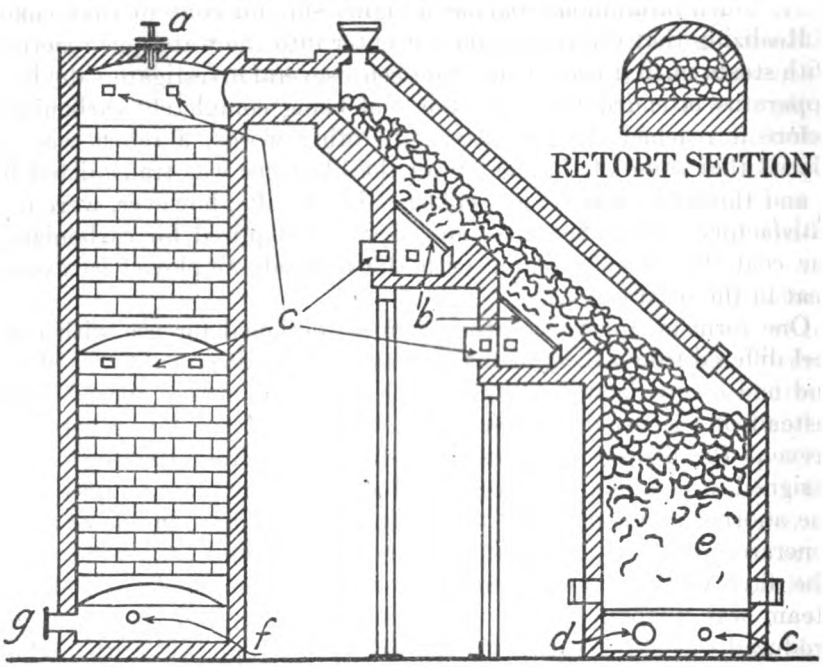

FIGURE 1.—**Rew soft-coal apparatus.** *a*, **oil;** *b*, **grate;** *c*, **air;** *d*, **gas;** *e*, **coke;** *f*, **steam;** *g*, **blast and gas outlet.**

grates in the coking chamber (retort). Secondary air was admitted at the top of the generator and at the regenerators. During the run the steam was admitted at the base of one regenerator where it was superheated; it passed upward through this regenerator, downward over the coking coal in No. 1 generator, upward through the fuel bed in No. 2 generator, over the coking coal in No. 2 retort, and then into No. 2 regenerator. Here oil was admitted from the top and the oil vapor and gas passed downward through the regenerator. In the succeeding run the direction of the flow was reversed; that is, the steam passed through No. 2 set first.

The difficulties with this apparatus were that not not enough coke was made to supply the generators; the coke produced was of an

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inferior grade, crumbling easily; and the coke or coking coal plugged the retort or stuck there, so that it frequently had to be pushed down by hand. Hence the labor required to operate this apparatus was excessive.

It is said[1] that the K. & A. apparatus (Kramers & Aarts) for blue water gas only has been extensively adopted in Europe. This apparatus has a double generator with a regenerator between, and its operation is as follows: Both generators are blasted and the regenerator (checker chamber) is heated by the combustion of the blast gas. Steam is then forced up through generator No. 1, through the regenerator and down through generator No. 2. On the following run the steam passes through generator No. 2 first. Advantage is taken of a deep fuel bed during the run, whereas a shallow fuel bed is used during the blow. Many attempts have been made by others to obtain this result. The generators are sometimes arranged so that by the movement of a lever during the run they can be set for operating in parallel or series. Thus under a heavy load they can be operated in parallel and produce more gas per unit of time. Operating this way deeper fuel beds are maintained in the generators than otherwise.

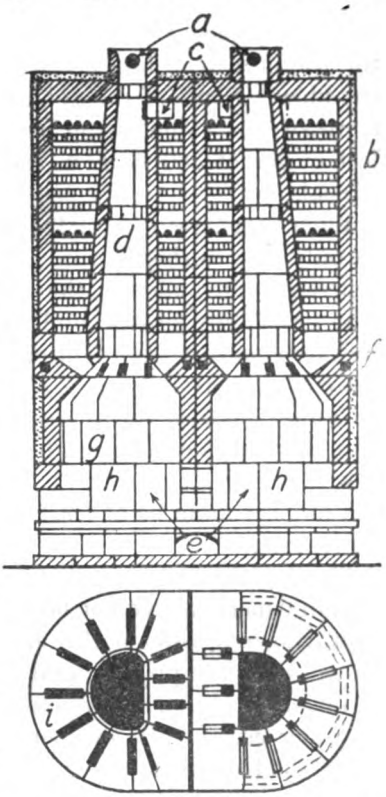

FIGURE 2.—**Smith's modification of the Kramers & Aarts patents.** *a*, **gas outlet;** *b*, **regenerator;** *c*, **outlet to stack, also steam and circulating gas inlet;** *d*, **retort;** *e*, **blast inlet;** *f*, **secondary air;** *g*, **hot coke;** *h*, **air;** *i*, **nostril.**

The Smith modification of the K. & A. process, shown in figure 2, is designed for the use of coking coal as generator fuel. It utilizes the double generator principle and has two coal carbonizing retorts into which the coal is fed and from which the coked coal passes into the generators. Figure 2 shows a vertical section and a horizontal section of this apparatus.

Both generators are blasted at the same time. The blast gas does not travel through the coking coal, but through the nostrils and up through the checker work or regenerators and out the stack. It is

[1] Meade, Alwyne, Modern gas works practice, 1916.

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said[2] that the blast gas passing through the nostrils contains an average of 10 per cent CO. This is burned in the checker chambers by the admission of secondary air. The blast lasts usually for a little more than a minute. The steam for the run is admitted at the top of regenerator on one side only; it passes down through the regenerator, through the first generator, through the second generator, and then through the carbonizing retort over the second generator. Its direction is reversed after the subsequent blast. Advantage is taken of the use of a deep fuel bed during the run and a shallow one during the blow. Some of the volatile matter of the coal is saved and thus increases the value of the blue gas. It is claimed that 60,000 cubic feet of gas of 380 B. t. u. are obtained from 1 ton (2,240 pounds) of coal.

Each regenerator is fitted with a spray, but the oil is admitted to only one during a run. The oil enters at the top of the regenerator surrounding the top of the retort, through which the blue gas finally passes, and the oil vapor passes down through the checker chamber (regenerator), through the nostrils, then up through the coking coal and out. A one-minute blast and five-minute run are approximately the average cycle employed. It is claimed further that the coal is carbonized before it has passed two-thirds of the way down through the retort. The steam consumption per thousand feet of gas should be at least as low as in modern practice with single generators.

The recent changes in the design of water-gas apparatus commonly used in America have not been so radical, consisting, in fact, of minor improvements which make operation easier, give the gas maker better control over the process, and decrease the initial cost of the set, but do not alter the primary conditions. One of the present tendencies is to increase the size of openings and shell connections, thus diminishing the back pressure or the resistance to the passage of gas. This is necessitated in part by the recent inclination among gas engineers to use high-blast pressures and a greater volume of air blast per minute in an effort to increase the capacity of the set. Changes in the design of hot valves and other appurtenances to a water-gas set are frequently made.

Plate I, *A*, shows a common type of water-gas set in general use at present. The connections and the stack valve are a little larger in the latest design of this set. Plate I, *B*, shows the operating floor and control valves and gages for this set.

Little information seems to be obtainable as to the reasons for the selection of the present form and shape of water-gas sets. There are many obvious reasons why the shells should be round and not

[2] Meade, Alwyne, work cited, p. 9.

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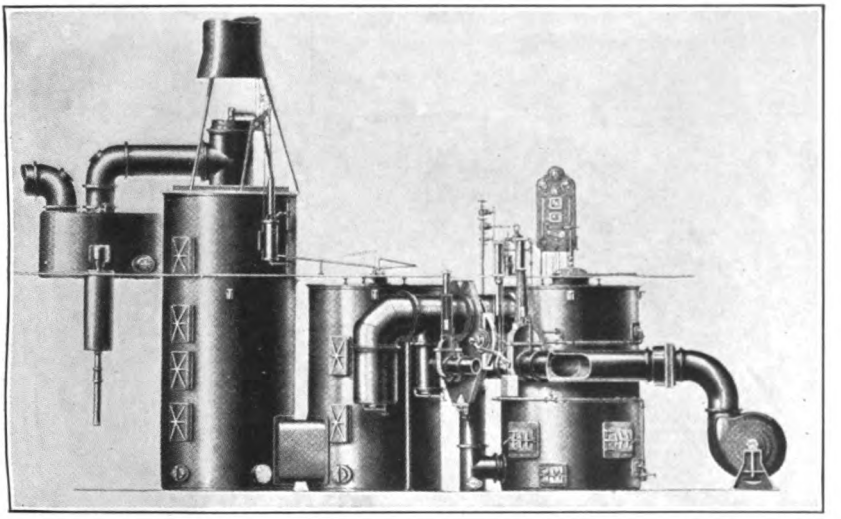
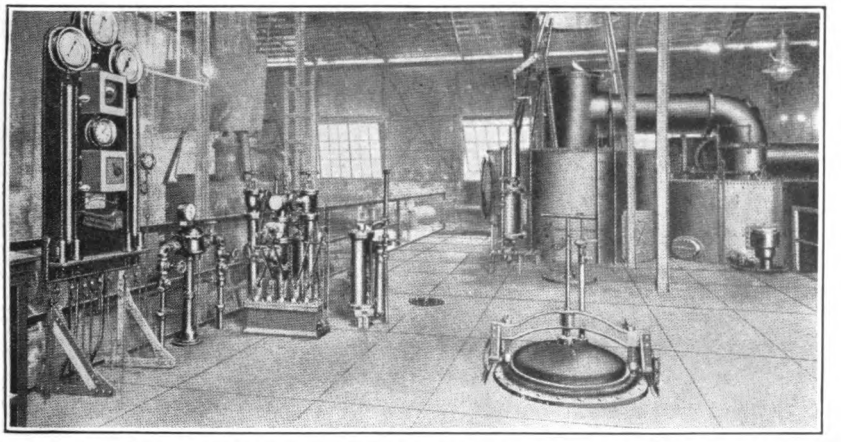


A. COMMON TYPE OF WATER-GAS SET IN USE AT PRESENT.



B. OPERATING FLOOR WITH CONTROL VALVES AND GAGE FOR ABOVE SET.

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square, and for similar details, but the selection of a given height or diameter, seems to have been more the outcome of experience with various sizes than the result of calculation. Some of the factors that help to control the size of the checker chambers are as follows:

1. Capacity desired per unit of time.
2. Time of contact of the oil with checker brick.
3. Volume of blue gas in which oil is cracked.
4. Heat available in generator blast gas for heating checker chambers.
5. Oil required per thousand feet to enrich the blue gas or to maintain the standard of gas.
6. Height of building.
7. Height of operating (charging) floor.
8. Results of experiments with sets of different size.
9. Draft on generator.
10. Accessibility for rapid repairing, recheckering or relining.

The generator design depends more on these factors:

1. The kind, nature, size, and quality of the fuel to be used, including fusibility of the ash.
2. The quality and quantity of steam available.
3. The quantity of air and its temperature (hot or cold).
4. Volume of blue gas required per unit of time.
5. Resistance of the fuel to the introduction of air blast.
6. Height of floor and building.
7. Time of contact required for the steam with the incandescent fuel to produce good blue gas.
8. Accessibility for cleaning and charging, and for observing and controlling the operation.
9. Experience with generators of different sizes.

Although the chief difficulties found in using Central District coals are due to generator conditions, it is evident that changes that will solve these problems will very likely modify the first five of the factors listed above as affecting checker-chamber design. In this paper the generator is given chief consideration, but the relations and requirements of the various parts of the set have not been disregarded.

DISTRIBUTION OF HEAT IN A WATER-GAS SET.

The relative amounts of fuel consumed for heating the checker chambers and heating the generator during the blast, and the quantity actually consumed during the run, can best be pictured when the figures for a heat balance are studied. Any such set of figures will necessarily be applicable only when conditions are the same as assumed in the original calculation, and when using the same kind

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of fuel. The variation, however, is not extremely great for small differences in the gas standard, hence it is the intention here merely to arrive at an approximate heat balance to illustrate wherein the fuel saving can be made, using bituminous coal as generator fuel, when making gas in a water-gas set especially suited for the fuel, and to show where the heat losses appear when high volatile coal replaces coke fuel. Although the total fuel used per thousand feet depends on a number of variables, the actual carbon equivalent of a given amount of blue gas is quite a definite thing when the blue gas does not contain any appreciable amount of volatile matter from the fuel. The fuel per thousand feet varies according to the number of hours the set is operated per day, hence certain assumptions have to be made in arriving at even an approximate figure. The assumed conditions here are as follows:

Based on:

Consumption of—	Per 1,000 feet of carbureted gas.
Fuel-coke (13,500 B. t. u. per pound)..... pounds..	30
Steam (at 100 pounds pressure)..... do....	35
Oil (pounds per gallon, 7.3)..... gallons..	3.2
Average temperatures of—	° F.
Blast gas leaving stack.....	1,600
Carbureted gas leaving set.....	1,300
Carbureter.....	1,350
Superheater.....	1,400
Ash withdrawn.....	1,500

Ash in fuel, 7 per cent.

The two chief reactions that take place are as follows:

$$(1)\quad C+H_2O=CO+H_2$$
$$(2)\quad C+2H_2O=CO_2+2H_2$$

Reaction (2) always takes place to a limited extent, varying in different plants according to the operating conditions, and can not be stated in terms that answer for all conditions. It may be assumed, however, that reaction (1) or its equivalent takes place to the extent of 90 per cent and reaction (2) takes place to the extent of 10 per cent. This assumption is based on the analysis of the blue gas at the generator lid.

Analysis of equation 1 gives the following:

$C+H_2O=CO+H_2$=378 cu. ft. CO+380 cu. ft. H_2
Roughly, 12 pounds+18 pounds=28 pounds+2 pounds

The combination of 12 pounds of carbon with 18 pounds of water as in this equation results in the formation of 758 cubic feet of gas which is 100 per cent combustible and has an average gross heating value of 325 B. t. u. per cubic foot.

The heat reaction for the equation is:	B. t. u.
12 lbs. carbon is capable of furnishing on complete combustion (12×14,544)..... =	174,528
28 lbs. CO contains heat of combustion equivalent to (28×4,368)=122,30 B. t. u.....	=246,334
2 lbs. H_2 contains (2.0×61,523) (2.016 actually used instead of 2, as 1.008 is atomic weight of H_2)=124,030 B. t. u.....	

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		B. t. u.
Heat absorbed	=	71,806
Assume that the water is steam at 100 lbs. pressure—		
Then the heat furnished by the steam is (18.016×1,161)	=	20,916
Heat absorbed from generator by reaction (1) without consideration of the temperature of the gas	=	50,890

Additional heat is absorbed from the generator because of the sensible heat of the gases leaving the generator. Assume that the blue gas leaves the generator at 1,300° F., then:

Heat required to raise 28 lbs. CO from 60° to 1,300° F.=8,901 B. t. u.

Heat required to raise 2.016 lbs. H_2 from 60° to 1,300° F.=8,902 B. t. u.

	Mean specific heat.	Weight.	Temperature, ° F.	B. t. u.
H_2	3.561	2.016 lbs.	(1,300−60)	8,902
CO	.2564	28.0 lbs.	(1,300−60)	8,901

		17,803
Heat actually used during run to satisfy reaction (1)		68,693

Radiation, not considered here.

Analysis of reaction (2) gives the following:

$$C+2H_2O=CO_2+2H_2$$

12 lbs.+36.032 lbs.=44 lbs.+4.032 lbs.

=378 cu. ft. CO_2+760 cu. ft. H_2

=1,138 cu. ft. of gas.

One-third of the gas produced by (2) is CO_2 and is combustible.

The thermal reaction is:

		B. t. u.
Heat generated—C to CO_2=(12×14,544)	=	174,528
Heat of combustion of 4.032 lbs. H_2=(4×61,523)	=	248,060
Heat absorbed by the reaction	=	73,532
Heat in the steam at 100 lbs. pressure is (36.32×1,161)	=	41,833
Heat absorbed from the fuel by the reaction	=	31,699

The sensible heat of the gas is—

	Mean specific heat.	Weight.	Temperature, ° F.	B. t. u.
CO_2	.2383	44	(1,300−60)	13,002
H_2	3.561	4.032	(1,300−60)	17,803

	30,805	
Heat absorbed from generator	=	62,504

Radiation, etc., not considered here.

Considering reaction (1) and (2) together, (1) taking place to the extent of 90 per cent and (2) to the extent of 10 per cent, the following figures represent the combined reactions:

(1) 10.8 lbs. C+16.21 lbs. H_2O=25.2 lbs. CO+1.81 lbs. H_2

340 cu. ft. 341 cu. ft.

(2) 1.2 lbs. C+3.6 lbs. H_2O=4.4 lbs. CO_2+0.4 lbs. H_2

38 cu. ft. 75 cu. ft.

The bulk result is as follows:

	Per cent by volume.
25.2 lbs., or 340 cu. ft. CO	42.8
2.21 lbs., or 416 cu. ft. H_2	52.4
4.4 lbs., or 38 cu. ft. CO_2	4.8
794 cu. ft. blue gas	100

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The heating value of the blue gas may be calculated as follows:

	B. t. u.	Cubic feet.	B. t. u.
CO,	323.5	× 340	= 109,990
H_2,	326.2	× 416	= 135,699
CO_2,	0.0	× 38	= 000
		794	= 245,689

$$\frac{245,689}{794} = 309 \text{ B. t. u. per cu. ft.}$$

B. t. u. of the blue gas=309

CO_2 in the blue gas=4.8 per cent.

The combined equations (1) and (2) are:

(3) 12 lbs. C+19.18 lbs. H_2O=25.2 lbs. CO+4.4 lbs. CO_2+2.21 lbs. H_2.

The heat balance is:

	B. t. u.
Heat of combustion of 12 lbs. C=(12×14,544) =	174,528
Heat of combustion of 25.2 lbs. CO=(25.2×4,368)=110,073 Heat of combustion of 2.21 lbs. H_2=(2.21×61,523)=135,965 =	246,038
B. t. u. absorbed in the reaction =	71,510
Heat furnished by the steam at 100 lbs. pressure (boiler pressure) is (19.8×1,161)=22,988 =	22,988
Heat absorbed from the generator by reaction 3	48,522

The heat carried away as sensible heat of the gas may be calculated as follows:

	Weight.	Specific heat.	Temperature.	B. t. u.
CO_2=	4.4 lbs.	× .2382	×(1,300−60)	=1,300
CO =	25.2 lbs.	× .2564	×(1,300−60)	=8,012
H_2 =	2.21 lbs.	×3.561	×(1,300−60)	=9,758 = 19,070
Total heat absorbed from the generator during the run =				67,592

Total heat absorbed in pounds of fuel is 67,592 ÷ 13,500 = 5 pounds.

The total fuel used during the run and furnished by the generator is, then, the sum of 5 pounds and 12.92 pounds (12.92 being the fuel equivalent of 12 pounds of C) equal to 17.92 pounds.

This value represents the heat absorbed per 794 cubic feet of blue gas, which is approximately equivalent to 1,000 cubic feet of carbureted gas. Radiation losses and loss from excess steam are not included in the figures just presented, but will be mentioned later.

BLASTING REACTIONS.

The reactions during blasting are as follows:

(4) $C+O_2 = CO_2 = +14,544$ B. t. u. per pound of C.

(5) $C+CO_2 = 2CO = -5,840$ B. t. u. per pound of C consumed.

Reaction (4) is the prime reaction taking place during blasting. Reaction (5) takes place to a limited extent; it permits the heating of the checker chambers by internal combustion.

In common practice 1,500 cubic feet of air is required for each 1,000 cubic feet of carbureted gas (1,500 cubic feet of air as generator blast).

Considering these equations with reference to the heat of reaction and the bulk of the products formed we have the following equation for reaction (4):

(4) 12 lbs.C+{32 lbs.O_2=44 lbs.CO_2+(106.35 lbs.N_2) / 106.35 lbs.N_2}

12 lbs.C+1,806 cu. ft. air=378 cu. ft. CO_2+1,428 cu. ft. N_2

The heat generated is equivalent to, 12×14,544=174,528 B. t. u. = 174,528 B. t. u.

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The heat taken away from the generator in the blast gases is as follows:

Specific heat at 1,300° F.	Weight.	Temperature ° F.	B. t. u.
N_2 =0.2564	× 106.35 lbs.	× (1,300–60)	=33, 812
CO_2=0.2383	× 44	× (1,300–60)	=13, 001
			B. t. u.
Heat removed from generator as sensible heat in the blast gas			46, 813
Heat remaining in generator (stored)			127, 715

Considering equation (5) similarly we have:

(5) 12 lbs.C+44 lbs.CO_2+(106.35 lbs.N_2)=56 lbs.CO+(106.35 lbs.N_2)
378 cu. ft. 1,428 cu. ft. 481 cu. ft. 1,428 cu. ft.

Inasmuch as these two reactions occur simultaneously, though in different parts of the fuel bed, they can be considered in combination, as equations (1) and (2) were, in the proportions in which they take place. On the assumption that the blast gases average 10 per cent CO_2 and that CO_2, N_2, and CO are the only gases present, reactions (4) and (5) may be expressed as follows:

Average analysis of blast gas:

CO_2	=10. 0 per cent by vol.	=14. 84 per cent by weight
CO	=18. 0 per cent by vol.	=17. 00 per cent by weight
N_2	=72. 0 per cent by vol.	=68. 16 per cent by weight
	100. 0 per cent	100. 00 per cent

The parts by weight of the different numbers of the combined equation are:

$$11.48 \text{ lbs.C}+\left\{\begin{matrix}68.16 \text{ lbs.}N_2\\20.36 \text{ lbs.}O_2\\\text{air}\end{matrix}\right\}=17.0 \text{ lbs.CO}+14.84 \text{ lbs.}CO_2+68.16 \text{ lbs. } N_2$$

The 1,500 cubic feet of air used per thousand feet of gas as generator blast is equivalent to 114.863 pounds of air, of which 26.57 pounds is O_2.

The equation may now be written:

$$14.68 \text{ lbs.C}+26.57 \text{ lbs.}O_2=22.00 \text{ lbs.CO}+19.25 \text{ lbs.}CO_2+88.29 \text{ lbs. } N_2$$

The heat balance is:

	B. t. u.
Heat of combustion of 14.68 lbs.C (14.68×14,544)	=213, 505
Heat of combustion of 22 lbs.CO (22.00×4,368)	= 96, 096
Heat liberated	=117, 409

The heat leaving the generator as sensible heat of the gas is:

Weight.	Specific heat.	Temperature ° F.	B. t. u.
CO_2 =19.25	× .2383	× (1,300–60)	= 5, 688
CO =22.00	× .2564	× (1,300–60)	= 6, 995
N_2 =88.29	× .2564	× (1,300–60)	=28, 070
			40, 753
Total heat developed in generator			=76, 656

Practically all of the heat of combustion of the blast gases leaving the generator is used to heat the checker chambers, proper allowance being made for the sensible heat of the products of combustion that pass out the stack. The equation for the production of generator gas as already given is:

$$14.68 \text{ lbs.C}+115.86 \text{ lbs. air}=22 \text{ lbs.CO}+19.25 \text{ lbs.}CO_2+88.29 \text{ lbs.}N_2$$

Complete combustion of this generator gas in the checker chambers gives:

$$22 \text{ lbs.CO}+54.34 \text{ lbs. air}+19.25 \text{ lbs.}CO_2=$$
$$=88.29 \text{ lbs.}N_2+53.82 \text{ lbs.}CO_2+130.06 \text{ lbs.}N_2$$

Mean specific heat.	Weight.	Temperature.	B. t. u.
N_2=0.2600	×130.06	×(1,600–60)	52, 076
CO_2=0.2483	× 53.82	×(1,600–60)	20, 580
Sensible heat in gas leaving stack			72, 656

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	B. t. u.
The heat evolved in the checker chambers is (22×4,368)	96,096
Sensible heat in stack gas	72,656
	23,440
Heat previously furnished as sensible heat of the blast gas from generator	40,753

Total heat available for use in the checker chambers after allowing for the sensible heat in the waste stack gas is, then ..... B. t. u. 64,193

This figure is based on perfect combustion of the blast gas without excess of air. The actual amount of heat that is absorbed from the checker work during the run is:

(*a*) The latent heat of vaporization of the oil used (7.3 lbs.×3.2)=23.36 lbs. of oil.

(*b*) The heat absorbed by the oil or cracked products on being heated to 1300° F.

		B. t. u.
The latent heat of evaporation is	130×23.3=3,029	
The heat absorbed by the oil on being heated to 1300° is:		
Pounds. 23.36 × Mean specific heat. .50 × Temperature. (1300–60)	=14,483	
Total absorbed by oil		B. t. u. 17,512

The difference between these figures, 64,320 and 17,512, or 46,808 B. t. u. is a part of the heat "lost" in the process.

	B. t. u.
It has been shown that the heat liberated in the generator during the blow and available for heating the generator fuel is	67,592
The heat absorbed from the generator fuel during the run is	76,656
Balance of heat or excess of available over absorbed	9,064
Heat lost from generator by radiation, convection, as heat in the ashes, and as heat absorbed by moisture in blast gas equals approximately this amount	B. t. u 9,064
The heat available (by theoretical combustion of the blast gas in the checker chambers without excess air) as shown, is per thousand feet.	B. t. u. 64,193
The heat actually required for carbureting the gas is, as shown, per thousand feet	17,512
Balance of available heat ..... per thousand feet	46,681
The heat "loss" from the checker chambers due to radiation, convection, and to imperfect combustion of the blast gas due to an excess or deficient supply of air equals approximately this amount	B. t. u. 46,681

		Per thousand feet of finished gas.
Fuel consumed during the run is	$12\times\left(\frac{14,544}{13,500}\right)$ pounds	12.92
Fuel consumed during blast	$14.68\times\left(\frac{14,544}{13,500}\right)$ ....do....	15.80
		28.72

There is still to be accounted for the heat absorbed by the excess steam which is heated to the temperature of the finished gas.

	Per thousand feet of finished gas.
This amount of fuel is equal to 6,977 B. t. u, or the equivalent of ....pounds..	0.52
Total fuel used, as shown .....do....	29.24
Actual fuel used .....do....	30
Unaccounted for .....do....	0.76

A small part of this 0.76 pound of fuel passes out as unburned fuel in the ash and clinker and as sensible heat of the ash. An additional small amount may be consumed, due to leaky hot valves and steam

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valves, and some of it is consumed during clinker periods by the natural draft through the set.

It has already been demonstrated that the loss, due to stack gases leaving the set at so high a temperature, can, to a considerable extent, be recovered by the use of a waste heat boiler for blast gas only. Some of the energy in the 0.76 pound of fuel shown above can likewise be recovered as well as the excess combustible gas produced during each blow if there is enough of the latter produced to make it worth while.

The recoverable energy from the blast gas when operating with coke fuel is contained in the 72,656 B. t. u., as shown above (which is the sensible heat in the stack gas), and in the 0.76 pound of fuel used in excess of the theoretical amount required. Considering that all of the recoverable energy is included in the 72,656 B. t. u., and that 60 per cent can be utilized for the actual evaporation of water, the amount of the latter evaporated per thousand feet is:

$\frac{72,656}{971} \times \frac{60}{100} = 44.9$ pounds per thousand feet operating with coke fuel.

When coal fuel (Central District bituminous coal) is used in place of coke the fuel used per thousand feet is at best 40 pounds when using the same method of operating. The heating value of this fuel is only 12,000 B. t. u. per pound, hence 30 pounds of coke are equivalent to 33.75 pounds of coal. This leaves a difference—(42 − 33.75)—of 8.25 pounds of coal per thousand feet, which to a great extent is represented in the blast gas as excess combustible matter when using coal generator fuel. It is desirable therefore in considering the design of a set for use with coal to keep in mind the fact that there is a difference in the fuel consumption per thousand feet when coal is substituted for coke in the generator, and that a large part of the increased fuel used can be recovered from the blast gas when means are provided.

Assuming the average heating value of blue gas from coke fuel to be 300 B. t. u. per cubic foot, and that of blue gas from bituminous coal fuel to be 335 B. t. u. per cubic foot, a difference of 35 B. t. u. appears for each cubic foot of blue gas. If, when operating with coal, the blue gas represents 80 per cent of the total carbureted gas, it is evident that for every 1,000 feet of such gas made the increased heating value of the 800 feet of blue gas present will be $35 \times 800 = 28,000$ B. t. u. The equivalent of this in pounds of coal (coal having a heating value of 12,000 B. t. u. per pound) is: $28,000 \div 12,000 = 2.33$ pounds. The additional amount of heat much of which can be recovered when bituminous coal is substituted for coke is, then, represented by the difference between these two figures—8.25 pounds and 2.33 pounds—or 5.92 pounds per thousand feet. Corrections to suit particular cases for differences in the percentage of blue

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gas present in the carbureted gas will of course slightly alter this value (5.92 pounds).

In deriving the actual amounts of fuel consumed during the complete operating cycle, in different parts of the set, the amounts of steam and secondary air used in excess of the theoretical amounts necessary to satisfy chemical equations must be considered. Some assumptions must necessarily be made in arriving at such a heat balance, for the following reasons: (1) It is impossible to say, at any given moment, what the average or maximum temperature is in the generator; (2) the temperatures of the gases leaving the generator and leaving the set are not constant; (3) the quality, quantity, and temperature of the steam used varies; (4) the temperature and degree of saturation of the blast air varies; (5) the amount of excess secondary air used during the blast is continually changing as the quality of the combustible blast gas changes; and (6) the temperature of the oil, atmosphere, etc., also affects the final results.

As it is considered good practice to make carbureted water gas using 30 pounds of good coke and 35 pounds of steam per 1,000 cubic feet of carbureted gas made, the calculations made for the distribution of heat as in actual operation are based on these figures.

SOME REQUISITES FOR THE EFFICIENT PRODUCTION OF GOOD WATER GAS IN QUANTITIES (COKE FUEL).

Requisites for efficiently producing good water gas in large quantities may be summarized as follows:

1. A large volume of fuel in a generator.
2. A deep fuel bed, consistent with the blast pressure and velocity.
3. The fuel must be incandescent and heated from 1,800° to 2,600° F.
4. The checker chambers for carbureting the gas should be large enough to gasify efficiently the requisite amounts of oil.
5. The checker chambers should be so constructed as to produce a natural draft in the generator when the latter is being cleaned or is not in operation.
6. The secondary air and generator blast gas should have ample means of mixing so as to avoid the use of an excess of secondary air to the carburetor.
7. The secondary air blasts should be so placed as to produce the desired temperatures in the checker chambers without overheating them in any part.
8. Openings between shells should be large enough to cause as little resistance as possible to the passage of gas through the set, and yet small enough to prevent a deposit of suspended matter by decrease in linear velocity.

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9. A dust catcher should be used between the generator and the carbureter.

10. Means should be provided to superheat the steam to as high a temperature as practical operation permits.

11. The waste space in the generators should be reduced to a minimum.

12. A means of spreading the fuel to the wall of the generator should be provided.

13. As handy a means as possible should be provided for clinker removal.

14. An appropriate operating cycle should be planned.

15. Sufficient steam should be available to avoid prolonging the run.

COKE AND COAL AS GENERATOR FUEL.

COKE.

In the operation of the ordinary water-gas set with coke fuel using ordinary air-blast pressure, more heat is produced as heat of combustion of the generator blow gas than is required for cracking and gasifying the oil. With the usual methods of blasting, however, this small difference is not troublesome, and in fact is frequently not noticeable.

Inasmuch as the blast pressure, quality of coke, and fusibility of the ash vary in different plants, it naturally follows that the operating temperatures (temperatures of fuel beds) may be different, and that the quality and quantity of the generator blast gas differ. No consideration has been given, in the figures above, to the volatile matter of the fuel. An appreciable amount of such volatile matter will increase the quality of the generator blast gas, which in turn leads to a decreased volume of blast and a colder generator or to an increased amount of waste combustible blast-gas, resulting in an increase in the generator fuel. This effect is due to the practice of burning all the blast gas in the checker chambers and of blasting just long enough to heat these chambers. This condition is aggravated by the fact that some of the volatile matter of the fuel passes into the blue gas during the run, increasing the heating value of the blue gas, and thereby diminishing the amount of oil required per 1,000 cubic feet, so that less of the heat available for heating the checker chambers is utilized. The amount of the increase in the heating value of the blue gas depends, of course, on the nature of the coke used. Parr has shown in a study of the low temperature distillation of coal that the gas coming off during the last stage of carbonization is chiefly hydrogen. A small amount of hydrogen will not increase the heating value of the blue gas appreciably, since it (hydrogen) has a heating value of only

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326 B. t. u. per cubic foot, and would itself have to be carbureted with the blue gas.

COAL.

Conditions are different when bituminous coal is used as generator fuel. Then the generator gas is so rich that on combustion heat enough is produced in the checker chambers for gassifying the oil before the generator is hot enough to make good blue gas. The coal cokes on the surface and heats superficially. When the run is on, the fuel naturally cools more quickly, and the result is that less blue gas is made per run. The heating value of the blue gas is richer, because of the volatile matter from the coal, and hence not only is less oil used per run, but less oil per 1,000 cubic feet. Thus the heat balance of the set is entirely upset by the use of coal.

Most of the other difficulties often attributed to the use of coal can in general be explained by the lower "temperatures" prevailing in the generator when bituminous coal is the generator fuel.

The mass of fuel in the generator is greater with coal than with coke, because of the difference in density of the two fuels. If the temperatures are the same in the fuel beds of two similar generators, one filled with coke and the other with coal, it is natural to suppose that during the run more heat would be available for the water gas reaction in the generator using coal. As coal must be coked, at least on the surface, before it is hot enough to combine with steam in the production of water gas, there are some difficulties to be overcome in the heating of Central District coals to as high a temperature as usually prevails with coke under the same conditions. Many of these coals contain 10 to 12 per cent of moisture, which on being driven off absorbs heat as latent heat of vaporization and as sensible heat. There are insulating areas, or surfaces, distributed as thin layers throughout the coal, which retard coking and heat transference in the direction perpendicular to the stratification. The volatile matter of the coal absorbs heat in the same way as the moisture does. This, however, is partly compensated for by the exothermic reaction taking place during coking, at 650° C. Increasing the volume of blast or blasting time will not entirely bring about the desired results, as the zone of complete combustion is at the base of the generator, which becomes overheated on excessive blasting. Also, this overblasting produces a great excess of generator blast gas.

It has been shown [3] that the reaction velocity for the decomposition of CO_2 by incandescent fuel ($CO_2 + C = 2CO$) is not the same at a

[3] Clement, J. K., Adams, L. H., and Haskins, C. N., Essential factors in the formation of producer gas, Bull. 7, Bureau of Mines, 1911, 58 pp.

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given temperature for all fuels. This is particularly true at the average temperature obtaining in a water-gas generator. The high ash content of the coke from Central District coals, and the appearance of the coke produced therefrom in the generator, leads the writer to believe that the rate of decomposition of CO_2 in the generator is slower with the coke so produced than with a good grade of gas coke (oven coke) made from Eastern coals.

The fact that the coke forms on the outer surface of the coal in a spongy porous layer permits an appreciable amount of the fuel to be superficially heated.

After blasting this fuel a very short time the blast gas is rich in CO owing to the high superficial temperature. On making a steam run this temperature drops more readily than that of a uniformly heated coke. Hence the "make" falls off rapidly and the percentage of CO_2 in the blue gas increases more rapidly during the run.

The hot zone in the generator occupies a smaller percentage by volume of the total fuel when these coals are used, and the tendency for unconsumed fuel to pass out with the ashes is much greater than when coke is used.

The successful utilization of Central District coal as generator fuel seems to require the conditions named herewith:

1. Higher temperatures in the fuel bed.
2. Larger body of completely heated fuel.
3. Increased production of blue gas per given amount of blast; or an increased amount of blast with an auxiliary utilization of the excess combustible blast gas.
4. A means of carbonizing the coal in the generator without the formation of a mat or cake in the upper part of the fuel bed.
5. The utilization of an increased air-blast pressure to offset the increased resistance of the coking fuel to the passage of air, or, the equivalent by a change in design of the set.
6. A means of control of clinker, particularly edgings.
7. A means of properly distributing the fuel in the generator.
8. A means of thoroughly atomizing the oil.
9. A generator so proportioned that the steam used during the run has ample time of contact with the incandescent fuel for the completion of the blue gas reaction.

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TABLE 1.—*Analyses of Illinois coals.*

County.	Coal bed.	Proximate analysis.				Sulphur.	CO_2.	Heating value, B. t. u.
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			
Franklin	6	[a] 9.04	34.46	48.73	7.77	0.68	0.23	11,946
		[b]	37.88	53.59	8.53	.74	.25	13,133
Do	6	[a] 9.05	34.45	48.75	7.75	.91	.37	11,923
		[b]	37.88	53.59	8.53	1.00	.41	13,108
Do	6	[a] 6.96	38.42	44.16	10.46	2.98	.92	11,848
		[b]	41.29	47.47	11.24	3.21	.99	12,733
Do	6	[a] 7.34	38.11	44.23	10.32	3.26	1.41	11,771
		[b]	41.13	47.73	11.14	3.51	1.53	12,703
Macoupin	6	[a] 4.29	39.09	37.21	9.41	4.13	.32	10,635
		[b]	45.60	43.42	10.98	4.82	.37	12,408
Do	6	[a] 13.77	38.69	36.74	10.80	4.37	.62	10,493
		[b]	44.86	42.62	12.52	5.07	.71	12,169
Do	6	[a] 14.73	36.26	36.11	12.90	4.62	.28	10,099
		[b]	42.53	42.34	15.13	5.42	.33	11,843
Perry	6	[a] 10.41	33.43	47.12	9.04	.88	.23	11,486
		[b]	37.32	52.59	10.09	.98	.25	12,822
Do	6	[a] 10.05	33.24	45.85	10.86	.93	.63	11,257
		[b]	36.94	50.98	12.08	1.04	.70	12,513
Do	6	[a] 12.76	35.18	44.32	7.74	1.66	.15	11,357
		[b]	41.79	49.34	8.87	1.90	.17	13,018
Williamson	6	[a] 9.35	32.83	50.07	7.75	1.05	.26	12,017
		[b]	36.21	55.24	8.55	1.16	.29	13,256
Do	6	[a] 10.96	33.14	45.86	10.04	1.72	.55	11,383
		[b]	37.24	51.49	11.27	1.93	.62	12,784

[a] Coal "as received." [b] Coal moisture-free.

DESIGN OF GENERATOR SET.

FIRST CONSIDERATIONS.

In designing a generator set best suited for Central District coal, several factors must be kept in mind. These coals differ greatly in moisture, volatile combustible, ash, and net heating value. Some of these differences are shown in Table 1. The coals differ also in the fusibility of their ash and in coking qualities.

Also, it is desirable that a set designed for the use of coal can be as successfully used with coke fuel. This is obviously true as regards both economy and fuel emergencies.

If possible, means should be provided whereby the sets already constructed can be equipped to utilize coal more efficiently or without objectionable features.

OPERATING POSSIBILITIES PERTAINING TO DESIGN.

From the foregoing considerations it might appear as though one of the following methods might improve the results obtained from using bituminous coking coal as generator fuel:

1. Using shorter operating cycles.

2. Using a coking chamber of some sort with or as a part of the generator, so that the coal can be coked more thoroughly before it enters the gas-making part of the generator.

3. Using a small amount of air with the steam during the run. This is a more practicable way of increasing the capacity of the set than the "blow-run" method.

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4. Using steam superheated to as high a temperature as possible.

5. Admitting the down-run steam lower in the generator, below the coking line.

6. Using a deeper fuel bed and an auxiliary means of utilizing the excess generator blast gas.

7. Providing an auxiliary means of utilizing the excess generator blast gas, so that generators can be used that are proportionately larger than the checker chambers that usually accompany them.

8. Employing a means of adding secondary air to the generator just at or below the coking line.

9. Employing a hot blast.

10. Radically changing from the present method of generating blue gas.

As regards the methods listed above, it appears that:

1. Usually it is not practicable to shorten the length of the operating cycle for the reason that the percentage of the time consumed in operating valves is materially increased. The proportional increase in time consumed in starting and stopping the runs and blows tends to reduce the make per unit of time.

2. The use of a coking chamber with the generator seems to the writer to be a possible means. Work already done demonstrates that such a chamber should be vertical and not inclined, and that it should be directly over the generator. Such a chamber could be heated from the outside, as is a retort in coal-gas manufacture, or from the inside by the generator blast.

Although the external heating and carbonization of the coal produces a better coke, enough heat can not be supplied by the generator as excess heat to carbonize the coal this way, particularly when the chamber is made of fire brick.

The internal heating of the coking coal by the generator blast gas increases the resistance to the passage of air and gas and reduces the capacity when the present type of fan blower is used. Therefore the depth of any such coking chamber can not be great, and the method of heating is restricted to either internal heating or a combination of internal and external heating.

3. The admission of air in small amounts with the steam seems to offer a means of increasing the production of blue gas. This is a more feasible way than the blow-run method adopted in the Streator experiments. It gives the coke a greater opportunity to impart its heat to the steam in the blue-gas reaction, and it also produces some gas, consisting of CO and N_2. A further advantage is that the air on the down runs will decrease the strong coking properties of the fresh green fuel and will mitigate the caking and matting difficulties. It will also permit the fuel in the top part of the generator to be heated to a higher temperature during the subsequent blasts. This

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could be done to good advantage when a means is provided for utilizing the heat of combustion of the excess combustible blast gas.

4. Although the heat as superheat in steam superheated to 1,400° F. is but a small per cent of the heat absorbed from the generator, superheating is particularly desirable when coal fuel is used, as it allows the production of more blue gas per run.

5. The use of down-run steam is both desirable and necessary, but an undesirable feature in such use with coal fuel is the retardation of the coking of the green coal. This may be eliminated to a considerable extent by admitting the steam below the coking line in the generator. It seems as though the coal could thus be raised to a high temperature sooner after charging.

6, 7. A deeper fuel bed will allow more time for the coking of the green fuel and will increase the time of contact between the fuel and the blue gas and the blast gas. Although increase in depth of the fuel bed is to be avoided if possible, some of the detrimental effects of a deeper fuel bed can be overcome by employing an auxiliary means of utilizing the excess generator blast gas (utilizing the heat of combustion as well as the sensible heat), as for example, a waste-heat boiler. If this is done a larger generator can be used with the present size checker chambers. This will require more heat in the checker chambers for carbureting the gas and will also bring the capacity up to the normal rated capacity with coke fuel.

8. By blowing secondary air into the generator just below the coking line, the percentage of combustible gas in the generator blast-gas can be reduced and the excess of heat from this source avoided. The temperature in the top part of the fuel bed can be materially increased and the production of blue gas can be improved. If the obstacles in the way of making this change can be eliminated, the difficulties charged to the use of coal can, in the main, be eliminated.

9. The employment of hot air as generator air-blast would allow more heat to be transmitted to the green coal in the upper part of the generator and would have the general effect of producing higher temperatures in the generator with a given quantity of air blast. This would to a great extent solve the problem, but is regarded with misgivings by many engineers on account of the danger of burning out the grates. Although the writer believes that preheated air could, with proper care and attention, be used satisfactorily with bituminous coal in the present apparatus, would eliminate the necessity of making so large a proportion of down runs and would reduce the loss of fuel in the ash, still in contemplating a hot blast it is natural to think of doing away with grate bars. This leads to the consideration of the following suggestion:

10. One change in design that might prove beneficial, not only in the use of coal fuel but also in the use of coke, is the elimination of

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grate bars and the slagging of the clinker by means of hot air blasts in a generator built along the lines of a blast furnace. The long clinkering periods could thus be eliminated and the operating efficiency increased.

Radical changes of this character will not be of as much immediate benefit as improvements that can be made by simpler changes in the present equipment. The condition in which many public service companies now find themselves seems to emphasize the desirability of making less radical changes at present in spite of greater possibilities offered by changes that are more sweeping. One of the leading manufacturers of water-gas apparatus informs the writer that the controlling factor in the purchase of any particular make of water-gas set seems to be the price.

DEPTH OF FUEL BED—TIME OF CONTACT.

For the complete decomposition of steam in the generator a temperature of 1,300° to 1,400° C. (2,372°–2,552° F.) in the fuel bed is desirable. A minimum temperature of 1,000° C. (1,832° F.) is good practice. This means that the temperature in the generator during a blast is between 1,832° F. and 2,552° F. The amount of CO produced in the blow gas depends on the rate of blow (time of contact) as well as the temperature. In estimating the time of contact consideration must be given to the fact that all the fuel in the generator is not heated to the desired high temperature. When the rate of air blast per minute per square foot of grate area is 160 cubic feet, or 2.7 feet per second, and the fuel depth is 7.5 feet, the time of contact may be figured as follows:

$$t=\frac{7.5}{2.7}=3.0 \text{ seconds (approximately).}$$

At an average temperature of 1,200° C. the blast gas will contain approximately 18 per cent of CO. One thousand feet of air blast produces, then, 110 cubic feet CO_2, 198 cubic feet CO, and 791 cubic feet N_2, a total of 1,099 cubic feet, or approximately 1,100 cubic feet of gas, carrying 64,152 B. t. u. as heat of combustion of CO. Evidently the time of contact is ample for the blow gas. The fuel bed could be much shallower and the time of contact less without decreasing the quality of the blow gas too much.

The time of contact of the steam and fuel during the run is an entirely different matter, for it is desirable to convert as much CO_2 into CO as possible. This is the exact opposite of the end desired in the blow-gas reaction. In the water-gas reaction it is desirable to have the fuel bed as deep and the temperature as high as possible; in other words, a long time of contact is desirable in order to decompose the greatest amount of steam with the formation of a minimum amount of CO_2.

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In present-day apparatus a deeper fuel bed is not practicable because, for the average rate of steam input, changes in temperature of the fuel bed have far greater effect than changes in time of contact. This is clear from the figures [4] given in Table 2. It is seen that at 1,300° C. (2,372° F.) and 1.63 seconds time of contact the gas produced is 7.7 per cent water vapor with only 0.3 per cent CO_2 in the dry gas. At 1,200° C. (2,192° F.) and with 2.13 seconds contact time the water content is 52.3 per cent and the CO_2 in the dry gas is 0.9 per cent. At 1,200° C. (2,192° F.) it takes 11 seconds contact time for the reaction to take place to the same extent that it takes place in less than 2 seconds at 1,300° C. (2,372° F.)

TABLE 2.—*Relation of temperature and time of contact to decomposition of steam by hot carbon.*

Temperature, °F.	Temperature, °C.	Time of contact, seconds.	H_2O content in total gas produced, per cent.	CO_2 in dry gas, per cent.
1,652	900	8.35	7.54	9.8
1,832	1,000	3.42	78.40	10.7
2,012	1,100	7.97	34.90	14.6
2,012	1,100	1.97	67.60	12.8
2,192	1,200	11.05	5.00	.3
2,192	1,200	4.48	17.00	.6
2,192	1,200	2.13	52.30	.9
2,372	1,300	4.32	.0	.4
2,372	1,300	2.25	2.1	.3
2,372	1,300	1.63	7.7	.3
2,372	1,300	1.24	17.4	.3

For a short time of contact a temperature of 1,300° C. (2,372° F.) or more should be maintained in the generator. Also, the time of contact of the steam and fuel at this temperature should not be less than two seconds and preferably not less than four seconds.

Calculating the time of actual contact between steam and fuel is not so simple as it might seem. Voids in the fuel bed, volume of steam, depth of fuel, concentration, etc., must be considered. The proportion of free space is not always the same and differs in different parts of the fuel bed. Only approximate value can be assigned to it.

During the course of the steam run the fuel temperature gradually diminishes and the percentage of moisture and of CO_2 in the gas increases. The total steam used during the run averages about 80 per cent in excess of the requirements of the blue-gas reaction. It is not particularly desirable to eliminate entirely the use of excess steam, as the carbureting oil cracks with a higher B. t. u. efficiency in the presence of blue gas containing 10 per cent of steam than in dry blue gas, and the efficiency is still greater with 20 per cent of steam in the blue gas. The excess steam decreases the amount of carbon deposited in the checker chambers. The make decreases as the excess steam increases and as the run progresses, whereas the

[4] Clement, J. K., Adams, L. H., and Haskins, C. N., Essential factors in the formation of producer gas: Bull. 7, Bureau of Mines. 1911. 58 pp.

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time of contact of the oil vapors with the checker chambers increases because of the smaller make of blue gas. With the present method of admitting oil to the checker chambers the increasing amount of excess steam as the run proceeds is quite desirable.

When bituminous coal is used with the usual colder generator, the time of contact of the steam with the incandescent fuel is less, as a smaller proportion of the fuel is incandescent. The Central District coals have ash with a low fusion temperature, and increasing the quantity of generator blast not only produces an excess of combustible blast gas but increases clinker troubles unless the temperature is maintained high enough to slag the ash. Hence in using Central District coals it is more desirable than ever that the fuel be uniformly heated and that the difference between the maximum and minimum temperatures be smaller.

CLINKERING.

Although clinker difficulties may be partly eliminated by the methods suggested, it is doubtful if they can be entirely eliminated. in that manner. When green fuel is charged into the generator, the lumps work their way to the wall and the fines pile up in the center. Thus the resistance to the passage of air through the fire increases in the middle of the generator while it decreases toward the wall. The tendency is for the fuel at the wall to burn more rapidly and to clinker on the wall, forming what are termed "edgings." The tendency for blowholes to form is greater at the wall than elsewhere. To mitigate these troubles, the author suggests that:

1. The generator lid be made large enough to permit the use of a fuel spreader that will efficiently spread the fuel.
2. An efficient fuel spreader be used.
3. Consideration be given the shape of wall in the design of a new generator.

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